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FOR

AUTOMATED ANALYSIS OF TURBINE COMPONENT THERMAL RESPONSE

Inventor(s):

William T. Brown
Brian A. Dalio

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William T. Brown
Brian A. Dalio

FIELD OF THE INVENTION

The invention relates to the field of infrared (IR) inspection of turbine components, such as turbine blades, turbine vanes, and other turbine items of the like having internal passages for cooling or other liquid/gas flow. More specifically, the invention relates to automated analysis of the thermal response of a turbine component to application of thermal stimuli to the turbine component by an IR inspection system to inspect the turbine component.

BACKGROUND OF THE INVENTION

Failure of a turbine component, such as a blade or a vane is costly, and may even be catastrophic. Accordingly, manufacturing a turbine component involves precision casting and machining processes, as each of these processes may introduce variables that affect the quality of the component, and in turn, its performance and reliability.

During the casting process, variables such as core misalignment, inclusions, and the like, can introduce casting defects into the components. Often times, these casting defects in turn may affect the machining process, resulting in machining defects, as well.

For example, a turbine component may include features such as cooling channels and holes. Cooling channels are internal features of the component through which coolants (e.g. in the form of gases) may flow. Because of the internal nature of the cooling channels, cooling channels are, often times, formed during the casting process utilizing casting cores. Defects, such as core misalignments may result in incorrectly formed, sized or blocked cooling channels.

The cooling holes allow the coolant flowing through the component to be exhausted out of the component. The dimension of the cooling holes may be in the range of 10ths of millimeters. Because of the small dimension of the cooling holes, often times, the cooling holes are machined into the component after the casting process. In order to control the precision of machining the cooling holes, an automated process may be utilized for the physical drilling of the holes, such as computerized numerically controlled (CNC) machine.

Drilling the cooling holes by CNC machine involves the CNC machine determining the exact position of the cooling holes in three-dimensional space, accounting for dimensional tolerances. If casting defects, such as core misalignments, affect the dimensions of the component to the extent that the dimensional tolerances are exceeded, the cooling holes may not be drilled properly.

Recently, inspection methods involving thermal signatures of materials, in particular, infrared (IR) detection imaging, are being utilized to inspect and detect defects in the manufacturing of turbine components. A turbine component

inspection method utilizing IR imaging involves applying differential thermal stimuli to the turbine components. Often times, applying differential thermal stimuli involves delivering a first thermal stimulus, such as a gas, at a high temperature to the component, and then, following the high temperature thermal stimulus, delivering a second thermal stimulus, such as a gas, at a cold temperature (i.e., cold, relative to the high temperature thermal stimulus) to the turbine component. An example of an IR inspection apparatus may be found in co-pending U.S. Provisional Pat. Application No. <insert number>, titled AN IMPROVED TURBINE COMPONENT INSPECTION SYSTEM, filed on November 1, 2001, and having at least partial common inventorship with the present application. The application is incorporated herein in its entirety by reference.

To ensure the high precision turbine components are inspected properly, the inspection itself, including e.g. the application of the thermal stimulus, is preferably performed with great precision each time, with the inspection system properly calibrated. Moreover, minimal to virtually no judgment should be required of the operators, to avoid human error. Prior known systems all suffer from varying degrees of not able to ensure consistent application of thermal stimuli to inspections of different turbine components or different inspections of the same turbine component. Moreover, too often, too much operator judgment is required in determining whether a turbine component passed or failed an inspection. Thus, a computer assisted method, including automated analysis of

the turbine components' thermal response to the applied thermal stimuli, and automated pass/fail conclusion, is desired.

SUMMARY OF INVENTION

In accordance with a first aspect of the present invention, thermal response of a turbine component to application of thermal stimuli to the thermal component is automatically analyzed by regions of interest.

In accordance with another aspect, each region is analyzed for conformance for a number of thermal response metrics. In various embodiments, the conformance is analyzed in an absolute sense, as well as relative to a reference/primary region.

In one embodiment, the thermal response metrics include the temperature threshold a particular region (e.g. the reference/primary region) exhibits a critical response size, and that the sub-region achieving the critical response size at the temperature threshold also has a critical shape.

In one embodiment, the analyses are performed using the pixel values of the constituting pixels of a picture frame of the turbine component's thermal response.

In accordance with yet another aspect, a binary passed or failed conclusion is reached based on the results of the automated analyses.

In one embodiment, a computing apparatus is equipped with executable instructions designed to perform the automated analyses.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings, in which the like references indicate similar elements and in which:

Figure 1 illustrates an overview of the present invention;

Figures 2a-2c illustrate an exemplary pictorial frame of the thermal response of a turbine component to an application of thermal stimuli, an exemplary region of interest, and an exemplary thermal response with an exemplary region of interest respectively;

Figures 3a-3b illustrate operational flow of the relevant aspects of the automated turbine component thermal response analysis function of **Fig. 1** in further detail, in accordance with one embodiment; and

Figure 4 illustrates a computer system suitable for use to practice the present invention, in accordance with one embodiment.

DETAILED DESCRIPTION OF THE INVENTION

As summarized earlier, the present invention includes the provision of a function to a computing apparatus to automatically analyze the thermal response of a turbine component to application of thermal stimuli to the thermal component. In a preferred embodiment, the provided function is also advantageously equipped to draw a binary pass/fail conclusion based on the results of the automated analyses.

In the following description, various aspects of the invention will be described. However, it will be apparent that the invention may be practiced with only some or all described aspects. For purposes of explanation, specific numbers, materials and configurations are set forth in order to provide a thorough understanding of the invention. However, it will also be apparent that the invention may be practiced without the specific details. In other instances, well-known features are omitted or simplified in order not to obscure the invention.

Parts of the description will be presented in terms of operations performed by a digital system, using terms such as data, pixel, pixel values, determining, and the like, consistent with the manner commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. As well understood by those skilled in the art, these quantities take the form of electrical, magnetic, or optical signals capable of being stored, transferred, combined, and otherwise manipulated through mechanical, electrical, and optical components of the digital system. The term digital system includes general purpose as well as special purpose data processing machines, systems, and the like, that are standalone, adjunct or embedded.

Various operations will be described as multiple discrete steps in turn, in a manner that is most helpful in understanding the present invention, however, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation, and selected ones of these operations may also be performed in parallel.

Further, the description repeatedly uses the phrase "in one embodiment", which ordinarily does not refer to the same embodiment, although it may.

Overview

Referring now to **Figure 1**, wherein a block diagram illustrating an overview of the present invention is shown. As illustrated, turbine component inspection system **100**, used to thermally inspect turbine component **108**, comprises thermal stimulus application and thermal imaging subsystem **102**, augmented with control computer **103**. For the embodiment, control computer **103** includes in particular, automated thermal response analysis function **104** to automatically analyze the thermal response of turbine component **108** to application of thermal stimuli to turbine component **108** for inspecting turbine component **108**. As will be described in more detail below, in a preferred embodiment, automated thermal response analysis function **104** performs its analysis using pixel values of the pixel of a pictorial frame of the thermal response of turbine component **108** generated by thermal imaging subsystem **102**. More specifically, in the preferred embodiment, the analyses are performed

using the "peak" pictorial frame, which the pictorial frame generated at the moment in time when a reference point reaches the temperature of the "hot" thermal stimulus applied to turbine component **108**. In alternate embodiments, more than one frame or a frame other than the "peak" frame may be analyzed instead.

Turbine component **108** represents a broad range of components, such as turbine blades, turbine vanes or other turbine components of the like, having e.g. internal passages or cooling channels that lend themselves to thermal inspection, i.e. inspection through analysis of the thermal signatures of these turbine components responsive to application of thermal stimuli. Similarly, turbine component inspection system **100** represents a broad range of turbine component thermal inspection system, including but are not limited to the inspection system disclosed in the aforementioned co-pending patent application number <to be assigned>.

Thermal Image

Figure 2a illustrates an exemplary frame of a 2-D thermal image of the thermal response of a turbine component to thermal stimuli applied to the turbine component. The exemplary frame is one of a plurality of frames of thermal images of the thermal response of the turbine component as captured by thermal imaging subsystem **102**. As illustrated, the 2-D thermal image **200** comprises a number of groups of thermal contours **202a-202c** depicting the surface temperatures of the turbine component. Each thermal contour corresponds to a

temperature level. Typically, in a gray-scale display, the areas between the

thermal contours will take on different degrees of "grayness" corresponding to the

temperatures. In a multi-color display, the areas between the thermal contours

will assume different colors. In other words, the constituting pixels of the pictorial

frame are comprised of pixels with pixel values corresponding to the surface

temperatures of the turbine component.

For the embodiment, thermal imaging subsystem **102** simultaneously

captures the thermal response of turbine component **108** from three

perspectives, the pressure side, the suction side and the leading edge.

Accordingly, 2-D thermal image **200** is a composite image of the surface

temperatures of the turbine component as seen from these three perspectives,

i.e. the pressure side, the suction side and the leading edge perspective.

Further, in accordance with one aspect of the present invention, the

automatic thermal response analyses performed by thermal response analyses

function **104** are performed by regions of interest. Shown also in exemplary

thermal image **200** are five regions of interest **204a-204e** representing the

regions of interest at the pressure side and trailing edge (region **204a**), the

pressure side and leading edge (region **204b**), the leading edge (region **204c**),

the suction side and trailing edge (region **204d**), and the suction side and leading

edge (region **204e**).

The regions of interest are design dependent. That is, the regions of

interest vary between different turbine component designs. More specifically, the

regions of interest vary depending on the designs of the internal cooling

channels. The regions of the interest for a particular design are empirically determined, by examining and comparing known good turbine components of the design and known defecting turbine components of the design. Other techniques or information may also be employed to empirically select the regions of interest. Obviously, the larger the sample employed for making the empirical determination, the more likely the regions of interest will be well chosen. However, even if less than optimal choices are made for the regions of the interest, turbine component inspection may nevertheless benefit from the automated thermal response analyses of the present invention.

In one embodiment, each region of interest is specified to the automated thermal response analysis function **104** by specifying the coordinates of the critical points or vertices of the region. For example, for the illustrated exemplary rectangular regions of interest, the regions may be specified by specifying the coordinates of the four vertices of each of the rectangular region. Note that while for ease of understanding, only rectangular regions of interest are illustrated, the present invention may be practiced with regions of interest that are non-rectangular in shape.

Specification of the coordinates of the critical points or vertices defining a region to automated response analysis function **104** may be made via any one of a number of input techniques known in the art, including but not limited to comma separated values (CSV), and form based end user interface.

Figure 2b illustrates an exemplary 3-D depiction of the thermal response of the turbine component for the region of interest **204a**. The vertical axis (T) is

the temperature axis. Similar to the 2-D depiction, typically, each spatial layer between two temperature contours will assume a different "grayness" in a gray-scale display or a different color in a multi-color display.

Figure 2c illustrates an exemplary 2-D depiction of sub-region 212 within a region of interest. Sub-region 212 comprises pixels with pixel values greater than a corresponding temperature threshold. As will be described in more detail below, in a preferred embodiment of the present invention, automated thermal response analyses performed by automated thermal response analysis function 104 comprises analysis of a region of interest's conformance for a number of thermal response metrics. In the preferred embodiment, these thermal response metrics include temperature thresholds, the area size and shape of sub-region 212. That is, in the preferred embodiment, automated thermal response analysis function 104 analyzes the thermal response of the region of interest of turbine component 108 for whether the thermal response of the region of interest reaches a desired critical response at certain threshold temperature, and whether the reached thermal response is of a desired critical size.

In the preferred embodiment, area size analysis is performed by determining the number of pixels within the region of interest having pixel values greater than the pixel value corresponding to the temperature threshold. Further, shape analysis is performed, by computing and comparing the weighted moments of the sub-region in the x as well as the y direction. In one embodiment, for each direction (x or y), up to four moment orders, zero, first,

second, and third moment order are considered in performing the shape analysis. In alternate embodiments, more or less moment orders may be used.

The zero moment in the x direction is computed by summing the weights of the computational segments (such as segment 214) along the x-axis. The first moment in the x direction is computed by summing the products of the weights of the computational segments (such as segment **214**) multiplied by the corresponding centroids' distances along the x-axis. The second moment in the x direction is computed by summing the products of the weights of the computational segments (such as segment **214**) multiplied by the square of the corresponding centroids' distances along the x-axis. The third moment in the x direction is computed by summing the products of the weights of the computational segments (such as segment **214**) multiplied by the cubes of the centroids' distances along the x-axis. The corresponding moments in the y-direction are computed in a like manner.

Further, in one embodiment, the computed moment values are adjusted to compensate for the location of the centroid of the sub-region. In one embodiment, the adjusted moment values are normalized to "remove" it from the pixel domain. In yet another embodiment, invariant versions of the moment values (without directional orientations), with zooming and rotational effects removed, are derived from the normalized moment values.

Mathematically, the computations are given by the following formulas:

Moment calculations:

$$\text{moments}(\text{img}) := \begin{vmatrix} \text{rMax} \leftarrow \text{rows}(\text{img}) - 1 \\ \text{cMax} \leftarrow \text{cols}(\text{img}) - 1 \\[4pt] m_{0,0} \leftarrow \displaystyle\sum_{i=0}^{\text{rMax}} \sum_{j=0}^{\text{cMax}} \text{img}_{i,j} \\[4pt] m_{1,0} \leftarrow \displaystyle\sum_{i=0}^{\text{rMax}} \left(\sum_{j=0}^{\text{cMax}} \text{img}_{i,j} \right) \cdot i \\[4pt] m_{2,0} \leftarrow \displaystyle\sum_{i=0}^{\text{rMax}} \left(\sum_{j=0}^{\text{cMax}} \text{img}_{i,j} \right) \cdot i \cdot i \\[4pt] m_{3,0} \leftarrow \displaystyle\sum_{i=0}^{\text{rMax}} \left(\sum_{j=0}^{\text{cMax}} \text{img}_{i,j} \right) \cdot i \cdot i \cdot i \\[4pt] m_{0,1} \leftarrow \displaystyle\sum_{j=0}^{\text{cMax}} \left(\sum_{i=0}^{\text{rMax}} \text{img}_{i,j} \right) \cdot j \\[4pt] m_{0,2} \leftarrow \displaystyle\sum_{j=0}^{\text{cMax}} \left(\sum_{i=0}^{\text{rMax}} \text{img}_{i,j} \right) \cdot j \cdot j \\[4pt] m_{0,3} \leftarrow \displaystyle\sum_{j=0}^{\text{cMax}} \left(\sum_{i=0}^{\text{rMax}} \text{img}_{i,j} \right) \cdot j \cdot j \cdot j \\[4pt] m_{1,1} \leftarrow \displaystyle\sum_{i=0}^{\text{rMax}} \left(\sum_{j=0}^{\text{cMax}} \text{img}_{i,j} \cdot i \cdot j \right) \\[4pt] m_{1,2} \leftarrow \displaystyle\sum_{i=0}^{\text{rMax}} \left(\sum_{j=0}^{\text{cMax}} \text{img}_{i,j} \cdot i \cdot j \cdot j \right) \\[4pt] m_{2,1} \leftarrow \displaystyle\sum_{i=0}^{\text{rMax}} \left(\sum_{j=0}^{\text{cMax}} \text{img}_{i,j} \cdot i \cdot i \cdot j \right) \\[4pt] m \end{vmatrix}$$

where "img" is the thermal image with pixels of the sub-region have pixel values of "1", and pixels outside the sub-region having pixel values of "0";

$m_{i,j}$ stands for a moment value of ith order in the y-direction, jth order in the x-direction

Central Moments:

$$\text{cmoments(m)} := \begin{vmatrix} \mu_{0,0} \leftarrow m_{0,0} \\[4pt] \mu_{1,0} \leftarrow 0 \\[4pt] \mu_{0,1} \leftarrow 0 \\[10pt] \mu_{1,1} \leftarrow m_{1,1} - \dfrac{\left(m_{1,0} \cdot m_{0,1}\right)}{m_{0,0}} \\[16pt] \mu_{2,0} \leftarrow m_{2,0} - \dfrac{\left(m_{1,0} \cdot m_{1,0}\right)}{m_{0,0}} \\[16pt] \mu_{0,2} \leftarrow m_{0,2} - \dfrac{\left(m_{0,1} \cdot m_{0,1}\right)}{m_{0,0}} \\[16pt] Xc \leftarrow \dfrac{m_{1,0}}{m_{0,0}} \\[16pt] Yc \leftarrow \dfrac{m_{0,1}}{m_{0,0}} \\[12pt] \mu_{3,0} \leftarrow m_{3,0} - 3 \cdot Xc \cdot m_{2,0} + 2 \cdot m_{1,0} \cdot Xc \cdot Xc \\[6pt] \mu_{0,3} \leftarrow m_{0,3} - 3 \cdot Yc \cdot m_{0,2} + 2 \cdot m_{0,1} \cdot Yc \cdot Yc \\[6pt] \mu_{1,2} \leftarrow m_{1,2} - 2 \cdot Yc \cdot m_{1,1} - Xc \cdot m_{0,2} + 2 \cdot m_{1,0} \cdot Yc \cdot Yc \\[6pt] \mu_{2,1} \leftarrow m_{2,1} - 2 \cdot Xc \cdot m_{1,1} - Yc \cdot m_{2,0} + 2 \cdot m_{0,1} \cdot Xc \cdot Xc \\[6pt] \mu \end{vmatrix}$$

where $\mu_{i,j}$ stands for a "centralized" moment value of ith order in the y-direction, jth order in the x-direction;
"X_c" is the x-coordinate of the centroid;
"Y_c" is the y-coordinate of the centroid.

Normalized Central Moments:

$$\lambda(p,q) := \frac{(p+q)}{2} + 1$$

$$\text{norm}(\mu,p,q) := \frac{\mu_{p,q}}{\left[(\mu_{0,0})^{\lambda(p,q)}\right]}$$

$$\text{nmoments}(\mu) := \begin{vmatrix} \text{for } i \in 0..3 \\ \quad \text{for } j \in 0..3 \\ \quad\quad \eta_{i,j} \leftarrow \text{norm}(\mu,i,j) \\ \eta \end{vmatrix}$$

where $\eta_{i,j}$ stands for a "normalized" moment value of ith order in the y-direction, jth order in the x-direction;

Invariant moments:

$$\text{imoments}(\eta) := \begin{vmatrix} \phi_1 \leftarrow \eta_{2,0} + \eta_{0,2} \\ \phi_2 \leftarrow (\eta_{2,0} - \eta_{0,2})^2 + 4 \cdot (\eta_{1,1})^2 \\ \phi_3 \leftarrow (\eta_{3,0} - 3 \cdot \eta_{1,2})^2 + (3 \cdot \eta_{2,1} + \eta_{0,3})^2 \\ \phi_4 \leftarrow (\eta_{0,3} + \eta_{1,2})^2 + (\eta_{2,1} + \eta_{0,3})^2 \\ \phi \end{vmatrix}$$

where ϕ_k stands for an invariant moment value.

In one embodiment, the weight of each computational segment is the number of constituting pixels of the computational segment. The size of each computational segment is implementation dependent. A finer computational segment is employed when higher precision is desired. However a coarser computation segment may be employed instead, when relatively lower precision is acceptable.

In one embodiment, an acceptance range for each of the thermal metrics analyzed by automated thermal response function **104** is also specified to

automated thermal response function **104** for each region of interest. For example, for a reference/primary region, an acceptance range is specified for the temperature threshold the critical response area size is to be reached, and an acceptance range for the desired shape. For each other region, an acceptance range is specified for the critical response area size, and acceptance ranges are specified for the various moment values indicative of the desired critical shape.

In one embodiment, where the thermal metrics are analyzed for relative proportionality between a reference/primary region and a secondary region, an acceptance range is also specified for the relative proportionality for each of the thermal metrics analyzed by automated thermal response function **104** for each region.

In one embodiment, specification of these acceptance ranges for the thermal metrics for each region is made in conjunction with the specification of the region. For example, a region of interest may be specified along with the acceptance ranges of the thermal metrics as follows:

R = { Vertices[(x1, y1), (x2, y2), (x3, y3), (x4, y4)], Metric1(lab, uab), Metric2(lab, uab) ...}, where "lab" is lower acceptance boundary, and "uab" is upper acceptance boundary.

Again, the specifications may be made through any one of a number of input techniques known in art, including but not limited to comma separated values (CSV), and form based user interface.

Operation Flow

Figures 3a-3b illustrate the operation flow of the relevant aspects of automated thermal response analysis function **104**, in accordance with one embodiment. More specifically, **Fig. 3a** illustrates the operation flow of the automated thermal response analysis function **104** in analyzing a reference/primary region of interest (e.g. a region located at the pressure side and trailing edge of a turbine component), whereas **Fig. 3b** illustrates the operation flow of the automated thermal response analysis function **104** in analyzing a secondary region of interest (e.g. a region located at the pressure side and leading edge of a turbine component, or a region located at the suction side, trailing/leading edge of a turbine component or a region located at the leading edge of a turbine component).

As illustrated in **Fig. 3a**, for the reference/primary region of interest, automated thermal response analysis function **104** (hereinafter simply function **104**) first determines a temperature threshold at which a sub-region within the reference/primary region of interest reaches at least a critical thermal response or area size, block **302**. In one embodiment, the determination is made by first setting a working pixel value to an arbitrary high pixel value, and then analysis is made to determine how many pixels within the region of interest have pixel values greater than the current working pixel value. The number of pixels having pixel values greater than the current working pixel value is compared to the desired critical response area size. If the number of pixels having pixel values greater than the current working pixel value is less than the desired critical

response area size, the working pixel value is lower by a predetermined amount.

Upon doing so, analysis is made again to determine how many pixels within the

region of interest have pixel values greater than the current working pixel value.

The number of pixels having pixel values greater than the current working pixel

value is compared to the desired critical response area size. The process

continues in this manner until eventually the sub-region has an area size that

substantially equates to the desired critical response area size.

Continuing to refer to **Fig. 3a**, once the temperature threshold at which a

sub-region within the reference/primary region of interest reaches at least a

critical thermal response or area size is determined, function **104** determines

whether the temperature threshold is within the specified acceptance range,

block **304**.

Next, for the embodiment, function **104** determines the shape of the sub-

region constituted with pixels having "greater" pixel values, block **306**. In one

embodiment, as described earlier, function **104** determines the shape of the sub-

region by determining the moment values for a number of moment orders for

both the x and y directions (including the earlier described centroid

compensation, normalization, and invariant calculations if implemented). Upon

determining the shape of the sub-region, more specifically, the characteristic

moment values, function **104** determines based on the computed moment

values, whether the shape substantially equates to a desired shape, block **308**.

As illustrated in **Fig. 3b**, for a secondary region of interest, function **104**

first determines the number of pixels with pixel values greater than the

terminating pixel value of the reference/primary region, block **342**. Then function **104** determines the area size of the sub-region constituted with pixels having "greater" pixel values, block **344**. As before, function **104** determines the area size by determining the number of constituting pixels of the sub-region. Upon determining the area size of the sub-region, function **104** determines whether the area size substantially equates to a desired area size, block **346**. For the embodiment, function **104** further determines whether the area size is substantially proportional to the area size of a corresponding sub-region of the reference/primary region of interest, block **346**.

Next, for the embodiment, function **104** determines the shape of the sub-region constituted with pixels having "greater" pixel values, block **348**. As before, function **104** determines the shape of the sub-region by determining the moment values for a number of moment orders for both the x and y directions (including the earlier described centroid compensation, normalization, and invariant calculations if implemented). Upon determining the shape of the sub-region, function **104** determines based on the computed moment values, whether the shape substantially equates to a desired shape, block **350**. For the embodiment, function **104** further determines whether the shape substantially complements the shape of a corresponding sub-region of the reference/primary region of interest, block **350**.

Example Computer System

Figure 4 illustrates one embodiment of an exemplary digital system suitable for use as control computer **103** to practice the present invention. As shown, exemplary digital system **103** includes one or more processors **402** and system memory **404**. Additionally, system **400** includes mass storage devices **406** (such as diskette, hard drive, CDROM and so forth), input/output devices **408** (such as keyboard, cursor control and so forth) and communication interfaces **410** (such as network interface cards, modems and so forth). The elements are coupled to each other via system bus **412**, which represents one or more buses. In the case of multiple buses, the buses are bridged by one or more bus bridges (not shown). Each of these elements performs its conventional functions known in the art. In particular, system memory **404** and mass storage **406** are employed to store a working copy and a permanent copy of the programming instructions implementing the teachings of the present invention (automated thermal response analysis function **104**). The permanent copy of the programming instructions may be loaded into mass storage **406** in the factory, or in the field, through a distribution medium (not shown) or through communication interface **410** from a distribution server (not shown). The constitution of these elements **402-412** are known, and accordingly will not be further described.

In alternate embodiments, the present invention may be practiced in computing environment that spans multiple computing systems networked together locally or across a wide area, through private and/or public networks.

Conclusion and Epilog

Thus, a novel method and apparatus for automatically analyzing the thermal response of a turbine component to application of thermal stimuli, to

facilitate more accurate and consistent inspection of turbine components has been described. While the present invention has been described in terms of the above illustrated embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described. The present invention can be practiced with modification and alteration within the spirit and scope of the appended claims. The description is thus to be regarded as illustrative instead of restrictive on the present invention.